Forest Dragon 2: Large-Area Forest Growing Stock Volume Mapping in China, using space borne radar

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FOREST DRAGON 2: LARGE-AREA FOREST GROWING STOCK VOLUME MAPPING IN CHINA, USING SPACEBORNE RADAR

Johannes Reiche[(1)], Reik Leiterer[(1)], Oliver Cartus[(1)], Maurizio Santoro[(2)], Christiane Schmullius[(1)], Zengyuan Li[(3)],

[(1)] Department of Earth Observation, Friedrich-Schiller University Jena, Grietgasse 6, 07745 Jena, Germany;
Email: Johannes.Reiche, Reik.Leiterer, Oliver.Cartus, c.schmullius @uni-jena.de
[(2)] Gamma Remote Sensing, Worbstrasse 225, 3073 Gümligen, Switzerland;
Email: santoro@gamma-rs.ch
[(3)] Forest Remote Sensing Lab, Research Institute of Forest Resource Information Techniques, Chinese Academy of Forestry ,Wanshoushan Hou, Haidian, 1000091 Beijing, China;
Email: zengyuan.li@caf.ac.cn

ABSTRACT

The creation of large-area forest growing stock volume (GSV) maps of Northeast and Southeast China, based on ERS-1/2 tandem coherence data from the mid 1990s, was aim of the Forest DRAGON 1 project. The evaluation of the map products reveals a reasonable agreement above 70% in terms of forest/ non-forest when compared against freely available Earth Observation products for both NE and SE China. The assessment of forest cover and structure changes in China from the mid 1990s into the current decade is addressed by a pilot study at the regions of Daxinganling and Xiaoxinganling. A one-year stack (2007) of Envisat ASAR GMM data has been processed at 1-km pixel size with the BIOMASAR algorithm to obtain continuous GSV. Accordingly, the ERS-1/2 tandem data has been reprocessed to 1 km to allow an intercomparison of the two products, which in turn allowed observing scaling effects on the forest GSV.

1. INTRODUCTION

The forests of Northeast China and Southeast China, which represent one of the most important wood supplies in China, have been undergoing constant pressure for several decades. The existing forest resources are not considered adequate for the needs of the Chinese economy and livelihood of the Chinese people. The existing forest statistics in China differ significantly [1] and indicate a need to monitor the forests status and their development on a regular basis.

In [2] forest growing stock volume (GSV) (also named stem volume) maps were produced for Northeast (~1,5 Million km²) and Southeast China (~3 Million km²) at 50 m spatial resolution from ERS-1/2 tandem coherence data were presented (Fig. 1). The ERS-1/2 tandem datasets consisted of 223 and 407 image pairs for Northeast and Southeast China respectively and were acquired under a wide range of meteorological conditions and perpendicular baselines (0 – 400m) in all seasons between 1995 and 1998. A new classification approach, based on synergy between the optical remote sensing product MODIS Vegetation Continuous Fields and ERS-1/2 tandem coherence has been developed for automatic and seasonal-adaptive retrieval of forest GSV, which is able to cope with multi-seasonal and multi-baseline data. The procedure integrates the semi-empirical Interferometric Water Cloud Model and discriminates between four GSV classes (0-20, 20-50, 50-80 and >80 m³/ha) [2]. The methodology will be hereafter referred to as DRAGON algorithm.

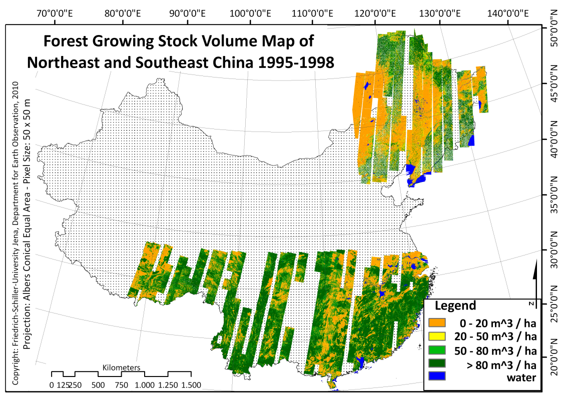

Figure 1. Forest GSV map of Northeast and Southeast China obtained from ERS-1/2 tandem coherence data for the years 1995 – 1998

For the validation a special multi-scale cross-comparison design mainly based on freely available Earth Observation products such as GLC2000, AVHRR UMD land cover classification, Globcover and the National Land Cover Database (NLCD) product of China, has been developed in consequence of lack of extensive in situ measurements. A reasonable agreement above 70 % between ERS-1/2 forest GSV map and the land cover datasets in terms of forest/ non-forest could be achieved for NE and SE China. A detailed description of the cross comparison methodology and results are given in [3]

To address the suitability of the Forest DRAGON products as potential input to global models (e.g. carbon models), it was decided to carry out a pilot study concerning an assessment of forest cover changes in China from the mid 1990s into the current decade at the regions of Daxinganling and Xiaoxinganling in Northeast China. Both regions have been characterized by forest fires and are a target for afforestation projects [4, 5]. Due to the lack of a high-resolution product for the mid-2000 equivalent to the ERS-based map and the encouraging results on forest GSV retrieval from hyper-temporal Envisat ASAR ScanSAR data [6, 7], it was decided to perform a comparison against GSV estimated from a one-year stack of Envisat ASAR images (Jan. 2007 – Feb. 2008) acquired in Global Monitoring Mode (GMM) at 1-km pixel size Accordingly, the ERS-1/2 tandem coherence data have been reprocessed to adhere to the coarse resolution of the ASAR GMM data, which in turn allowed observing scaling effects on the forest GSV.

The preliminary results of the pilot study at the regions of Daxinganling and Xiaoxinganling, analyzing forest cover changes between the mid 1990s and 2007/08 is presented in Section 2. The intercomparison of the map products, which will be done in terms of forest cover and forest structure changes, has not been concluded yet. However, an outlook is given in Section 3, where a summarizing conclusion is given.

2. FOREST COVER CHANGE PILOT STUDY

2.1. Study Area

The regions of Daxinganling (Greater Hinggan Mountains; 53°8' N, 123°4' E; ~200 x 200 km) and Xiaoxinganling (Lesser Hinggan Mountains; 47°10' N, 128°53' E; ~300 x 300 km) in Northeast China have been selected as the test area for the pilot study (Fig. 2).

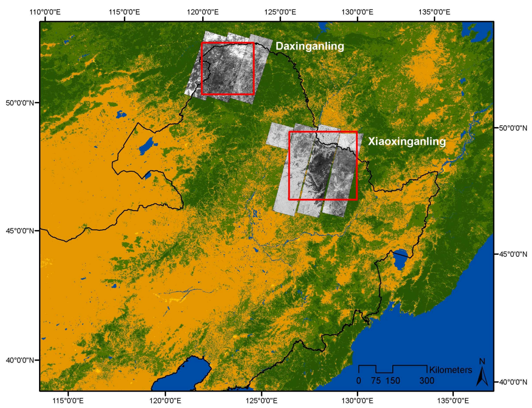

Figure 2. Location of the study regions of Daxinganling and Xiaoxinganling in Northeast China and the existing ERS-1/2 tandem data (interferometric SAR coherence) underlaid with the AVHRR Land Cover product.

Daxinganling is characterised by gentle topography and needle-leaf forest dominated by larch trees. In 1987 a forest fire [8] widely destroyed the forest areas, which since then have been characterised by both, natural regrowth and reforestation projects [5]. The GSV is approximately 200 m^3/ha. Xiaoxinganling is characterised by hilly terrain with an average slope of 10° and a low GSV, mostly below 200 m^3/ha.

2.2. ERS-1/2 Tandem Coherence Forest GSV (1995 - 1997)

A multi-seasonal ERS-1/2 dataset was available, consisting of 9 and 13 tandem pairs for Daxinganling and Xiaoxinganling respectively. The data was acquired between winter 1995 and autumn 1997 and the perpendicular baselines varied between 60 and 352 m.

The methodology consisted of interferometric processing of the ERS-1/2 tandem data to generate interferometric SAR coherence (Section 2.2.1) followed by model training and model inversion to retrieve forest GSV from the coherence (Section 2.2.2). Since the DRAGON algorithm [2] has only been applied at a 50 m resolution so far, scaling effects on the coherence estimates and on the retrieval were also investigated.

2.2.1. Interferometric Processing

Two basic approaches can be considered to process interferometric SAR coherence at 1 km scale for ERS-1/2 tandem images. The first approach considers the coherence estimation based on initially multi-looked (ML) ERS-1/2 images. To achieve an approximate pixel size of 1 km, ML factors of 40 in range and 200 in azimuth are used. The second approach consists of multi-looking the interferometric SAR coherence generated with a pixel spacing of 50 m (ML 2x10) with factors 20 and 20. Because the forest GSV is retrieved from coherence information, correct coherence estimation is essential for an accurate GSV retrieval. Both approaches have therefore been investigated with respect to scaling effects on the interferometric SAR coherence estimation.

The investigation was carried out for several ERS-1/2 tandem datasets located within the region of Xiaoxinganling and is summarized below using an example dataset (03/04 October 1997, Track 0461, Frame 2655) for illustration. Figure 3-1, 3-2 and 3-3 show the results obtained with the first method, where coherence images at 50 m (ML 2x10; estimation area (ea) 150 – 250 m), 500 m (ML 20x100; ea 1500 – 2500 m) and 1 km (ML 40x200; ea 3000 – 5000 m) are compared. The application of the second method, where the interferometric SAR coherence was initially processed to 50 m (ml 2x10, ea 150 – 250 m) and then multi-looked to achieve a final resolution of 500 m and 1 km, is illustrated in Figure 3-4 and 3-5.

The interferometric SAR coherence is estimated by averaging a number of pixels within a window to reduce the variance of the interferometric phase [9]. Due to coherent averaging over an area, low coherent areas lead to decreased coherence estimates in neighbouring regions. In particular, the first method is strongly affected by this effect as a result of the increasing coherence estimation area with decreasing pixel resolution (increasing ML factors) (Fig. 3-2 and 3-3). In consequence, this error would propagate into wrong GSV retrievals. Using the second method, this effect is minimized, since the coherence is estimated over a relatively small area (150 – 250 m) (Fig. 3-4 and 3-5) and then averaged. The scatter plots in Fig. 3-A and 3-B compare the coherence estimated with the two methods and highlight the clear underestimation of the interferometric SAR coherence by using the first method.

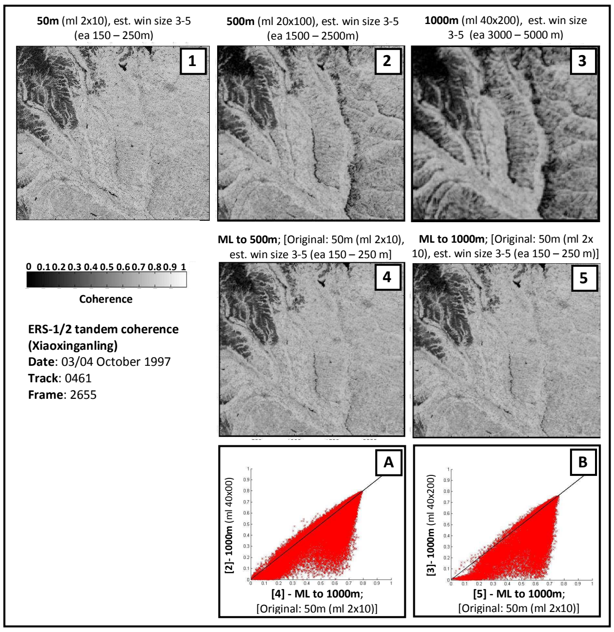

Figure 3. Comparison of interferometric SAR coherence estimates.

Based on these results, the second method was used for the interferometric processing of the ERS-1/2 tandem data, which is summarized below. The interferometric processing was done on frame-by-frame basis (100 x 100 km). It consisted of co-registration at sub-pixel level, multi-looking (2x10), common-band filtering and adaptive coherence estimation using window sizes between 3x3 and 5x5 pixels. For the common-band filtering a slope-adaptive approach that makes use of the SRTM-3 DEM was applied [10]. All coherence and backscatter images were geocoded using SRTM-3 DEM data and resampled to a pixel size of 50 x 50 m. During the geocoding, maps of slope angle, layover/shadow, pixel normalization and local incidence angle were produced. Finally, the coherence was multi-looked with factors 20 and 20 to 1 km pixel size.

2.2.2. Model Training and Forest GSV Retrieval

The DRAGON algorithm used for the retrieval of forest GSV from coherence is based on the Interferometric Water Cloud Model (IWCM) [11]. The IWCM describes the coherence of a forest as a sum of a ground and a vegetation contribution. It includes five unknowns that should be determined via model training, which usually relies on the availability of forest inventory data [12, 13]. In [2] a model training approach that is independent from inventory data was developed by supporting the estimation of the unknown model parameters by means of the MODIS Vegetation Continuous Field (VCF) tree cover product [2]. The VCF product provides global sub-pixel estimates of tree cover at 500 m pixel size [14]. The clear relationship between the ERS-1/2 tandem interferometric SAR coherence and the VCF product allows the estimation of four of the five model parameters by simply masking the coherence images for low (<10%) and high VCF (at least 70%) values. Respectively, γ_{gr} (ground coherence) and σ^0_{gr} (ground intensity) were estimated by masking areas characterized by low VCF values (<10%); γ_{veg} (ground coherence) and σ^0_{veg} (vegetation coherence) by masking areas of high VCF values (at least 70%). The remaining model parameter forest transmissivity β is set to 0.006 following the results on the estimation of this parameter using regression based model training with in situ data. For more details it is referred to [2].

The model training was conducted at 50 m resolution and then applied to the 1-km dataset to obtain the forest GSV. Since the model training is conducted on a frame-by-frame basis (100 x 100 km), the number of masked pixels representing areas of low and high VCF values strongly decreases at 1 km spatial resolution. Too few samples lead to an insufficient model estimate of γ_{gr}, σ^0_{gr}, γ_{veg} and σ^0_{veg} and hence to an inaccurate GSV retrieval.

For the VCF-based model training, a sufficient number of sample pixel for dense forest (VCF > 70 %) could be selected for most frames. In the case of too few sample pixels, the neighbouring frames have been included, which in turn enabled reasonable good model training results for the entire dataset. After the VCF-based model training at 50 m pixel spacing, the inversion of the model was carried out at the 1 km resolution. The retrieved GSV was then reparted in the four GSV classes (0-20, 20-50, 50-80 and >80 m^3/ha). In addition, for each image frame, two flag images representing the percentage of 50 m water pixel and the percentage of 50 m pixel with valid/non-valid information in each 1 km pixel were generated (Fig. 4). Pixels were labelled as non-valid in case of layover and shadow and when they were masked during the model training due to strong spatial decorrelation. For details on the quality flag and masking procedure it is referred to [2]. The percentage of water underneath a 1 km pixel was used to classify water in a reprocessing step (percentage of water > 10 %). Finally, a nearest-neighbour interpolation with a window size of 3x3 was applied to fill gaps of non-valid 1 km pixel. The interpolation procedure is not applied if less then 5 pixel (50 %) of the interpolation window show no information (Fig. 4).

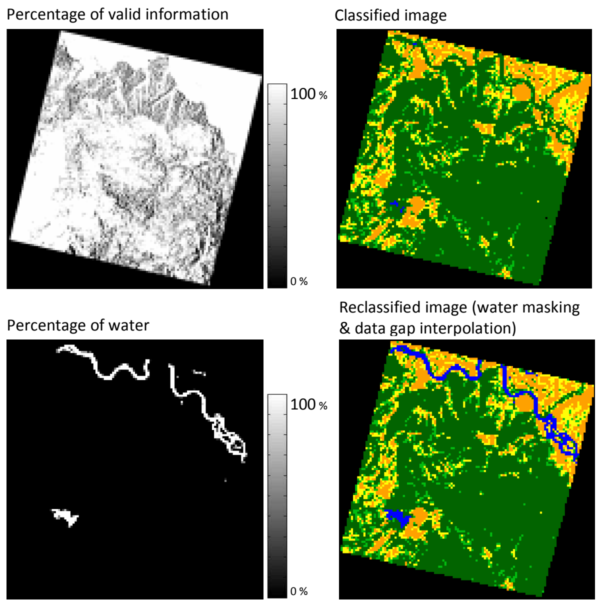

Figure 4. Classified image, corresponding flag files (percentage of valid information & percentage of water) and the final reclassified image (09/10 Jan. 96, Track 418, Frame 2619). The colour coding for the two maps on the right is described in Fig. 1.

Figure 5 shows the maps of forest GSV classes at 1 km pixel spacing for the regions of Daxinganling and Xiaoxinganling. It turned out that the described method (processing & interpolation) led to complete reduction of data gaps in mountainous regions, which is one of the major drawbacks of the 50 m ERS-1/2 forest GSV map [2].

The 1-km ERS-1/2 forest GSV map for Xiaoxinganling and Daxinganling presented reasonable agreement with all LC products. Compared to the original 50 m ERS-1/2 forest GSV product, slightly higher overall accuracies (OA) were obtained (Tab. 1, 2), which however do not seem to be statistically significant.

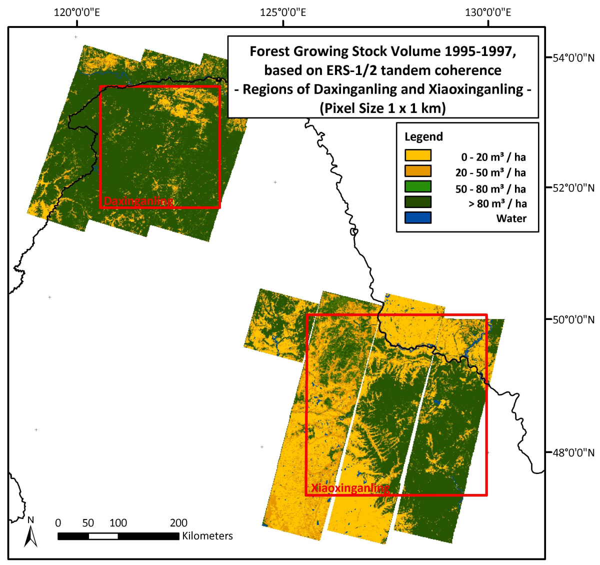

Figure 5. ERS-1/2 forest GSV 1995-1997 (1 km pixel size) of the regions of Daxinganling and Xiaoxinganling

Table 1. Overall agreement between the GSV map at 50 m and 1 km pixel size and the LC products for Xiaoxinganling based on aggregated forest/ non-forest classes

	OA ERS-1/2 GSV 50m	OA ERS-1/2 GSV 1 km
NLCD	0.80	0.80
GlobCover	0.81	0.85
VCF (> 15% CC)	0.87	0.89
GLC2000	0.80	0.83
AVHRR LCC	0.65	0.67

Table 2. Overall agreement between the GSV map at 50 m and 1 km pixel size and the LC products for Daxinganling based on aggregated forest/ non-forest classes

	OA ERS-1/2 GSV 50m	OA ERS-1/2 GSV 1 km
NLCD	0.72	0.73
GlobCover	0.77	0.78
VCF (> 15% CC)	0.90	0.91
GLC2000	0.88	0.89
AVHRR LCC	0.74	0.79

2.3. Envisat ASAR GMM Forest GSV (2007/08)

Mapping of forest biophysical parameters with radar data acquired during the current decade can take advantage from data acquired by a wealth of spaceborne sensors. Nonetheless, repeated global coverage is only ensured by one of these, Envisat ASAR operating in ScanSAR mode. Since 2005 Envisat ASAR operates in the background mission the ScanSAR mode, i.e. continuous observations at either 100 or 500 meter whenever no data request has been posted to ESA. This allowed the generation of large stacks of hyper-temporal data also thanks to the large swath width (400 km). It is not uncommon that a point on the ground has been imaged more than 300 times during one year.

The drawback of Envisat ASAR backscatter observations for forest monitoring is the short wavelength (5.6 cm). It is well known that the sensitivity of the backscatter to forest parameters decreases when going from unvegetated to dense forest conditions. A number of studies have indicated that multi-temporal combination of estimates of GSV can lead to an improved estimate with respect to individual images [12, 15]. This concept has been applied in the recently developed BIOMASAR algorithm. In a similar manner to the DRAGON algorithm, a novel aspect of the BIOMASAR algorithm is the independence from in situ reference data for calibrating the model used to invert backscatter measurements for retrieving forest GSV. For details on the approach it is referred to [6, 7].

The BIOMASAR algorithm has been applied to a one-year stack of repeated ASAR GMM images acquired between January 2007 and February 2008 over the two study areas. Figure 6 shows the ASAR GSV map for Xiaoxingaling (green tones) overlaid on the GLC2000 land-cover map.

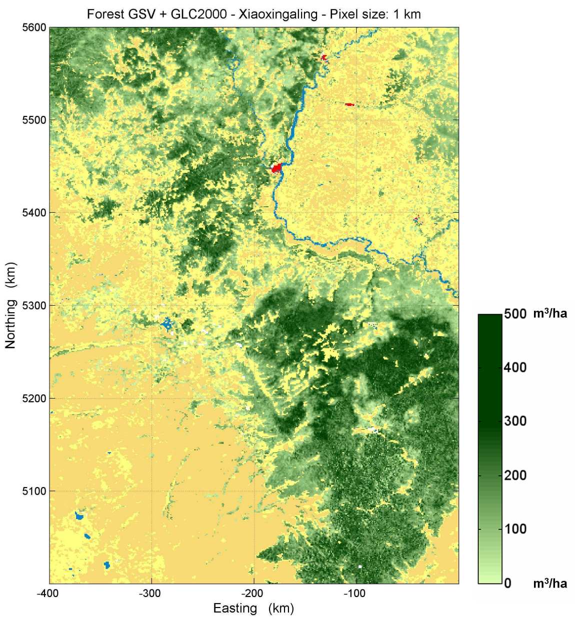

Figure 6. Continuous Envisat ASAR GMM GSV for the region of Xiaoxingaling. The ASAR data was acquired during 2007/08 and was processed to 1 km pixel size.

The assessment of the retrieval accuracy is hindered by the lack of in situ measurements. However, the plausibility could be checked by comparing the retrieved GSV values against the estimates of canopy cover percentage in the MODIS VCF product. Figure 7 shows a scatter plot of the BIOMASAR forest GSV (2007/08) and the VCF percentage tree cover 2005 (> 15%) for Xiaoxingaling. It appears that the VCF percentage tree cover saturates at ca. 100 m³/ha GSV, thus confirming the indications from several sites in the boreal zone [16] that radar observations are more related to forest structure, even at C-band.

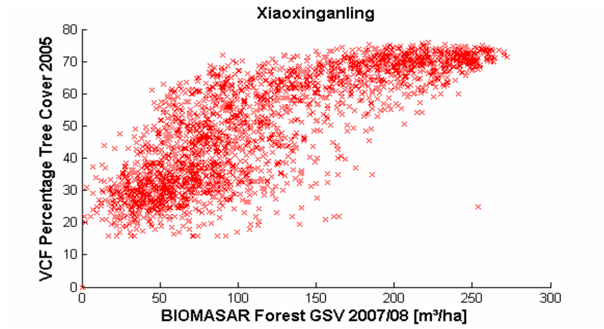

Figure 7. BIOMASAR forest GSV 2007/08 vs. VCF Percentage tree cover 2005 (Xiaoxinganling)

In order to allow an intercomparison with the forest ERS-1/2 GSV map of 1995-1997, the continuous forest GSV values have been reclassified into the four ERS-1/2 GSV classes (0-20, 20-50, 50-80 and >80 m³/ha) (Fig. 8). Preliminary analysis of the two forest GSV maps in terms of forest cover and structure change reveal patterns of both regrowth and deforestation.

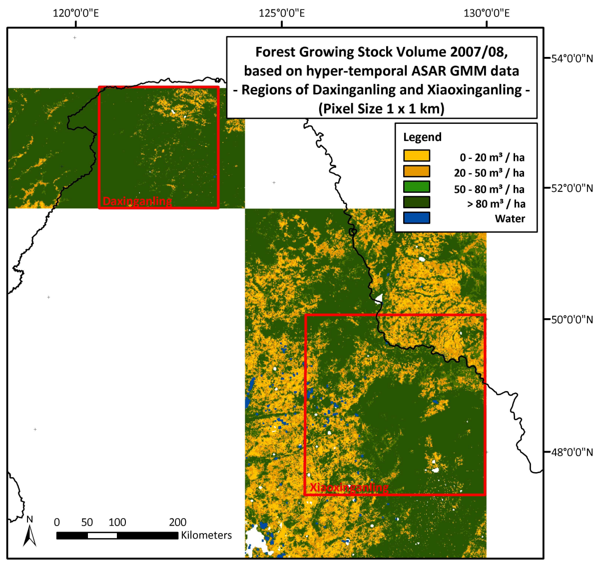

Figure 8. Envisat *ASAR GMM forest GSV 2007/08 (1 km pixel size) of Daxinganling and Xiaoxinganling regions reclassified to the four GSV classes used for the GSV retrieval using the ERS-1/2 tandem data*

3. CONCLUSION AND OUTLOOK

Topic of this paper was a pilot study at the regions of Daxinganling and Xiaoxinganling in Northeast China to assess forest cover and forest structure changes in China from the mid 1990s into the current decade using ERS and Envisat ASAR data. For this scope, the GSV product obtained from ERS-1/2 tandem coherence using the novel DRAGON algorithm for the years 1995-1998 has been compared to continuous estimates of GSV obtained from Envisat ASAR ScanSAR backscatter data. The limited information on forest parameters that can be achieved from the available Envisat ASAR data acquired at high resolution over China and the recent results on retrieval of forest GSV from hyper-temporal stacks of Envisat ASAR ScanSAR low resolution data justified this exercise.

The ERS-1/2 tandem data have been reprocessed to 1 km resolution to adhere with the pixel size of Envisat ASAR Global Monitoring Mode data, which is widely available over China. This in turn allowed observing scaling effects on the forest GSV derived from the ERS coherence data. The major result in this sense is the reduction of topography-induced gaps in the GSV map. At 1-km pixel size, extreme topography is smoothened which allowed the retrieval of GSV also in those areas that at 50-m were severely affected by spatial decorrelation. The inter-comparison between the low-resolution GSV map and freely available land-cover products showed an agreement of the same order as for the original 50-m maps. A one year stack of Envisat ASAR GMM (2007-2008) data at 1-km pixel size has been processed, using the BIOMASAR algorithm. The accuracy assessment is ongoing. The plausibility of the retrieved GSV has been so far checked against the canopy cover information in the MODIS VCF product, revealing a significant agreement. Interestingly, the VCF estimates saturate at about 100 m^3/ha, which seems to indicate that the ASAR-based GSV contains more information on forest structure.

First indications on forest cover change patterns seem to have been captured by the two SAR products. While plausible, the detected changes have not been confirmed yet. A major work of data and information collection of land-cover dynamics during the last decades is foreseen to be able to provide a detailed assessment of the detected changes

4. ACKNOWLEDGMENT

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